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Innovative Framework for Immersive Metrology

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Abstract

The combination of augmented reality and metrology could lead to immersive metrology which has the potential to radically change how part inspection is undertaken, and by doing so enhance the value adding capability of being able to dynamically inspect a part in situ without handling it. This paper presents a case for immersive metrology within the context of part inspection. A framework is proposed to enable integration of the critical elements of augmented reality for dimensional inspection of different case study parts.

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Keywords: Metrology; Augmented Reality; Human Computer Interaction; Verification and Validation; Measurement-assisted assembly

1. Introduction

Metrology is integral to every manufacturing operation. This can be in the form of traditional hard gauges for repetitive measurement of specified features, through to scanning methods that can capture multiple points on a given part surface. These methods gather information about the product either to qualify the conformance of the product to specifications or, in the case of reverse engineering applications to gain new knowledge. Typically, in manufacturing scenarios, metrology is undertaken within a quality department or, alternatively, within process, using in situ methods such as on machine inspection utilizing touch trigger probes, photogrammetry or non-contact high-fidelity scanning.

In parallel to developments in metrology, augmented reality has reached a maturity that enables it to be used within a manufacturing context. This new emerging technology enables the user to experience a richer and more immersive experience when digitally interacting with their environment.

Within an engineering context augmented reality is being used to help engineers design more efficiently using a

combination of interaction and immersion within dedicated computer aided design environment. New technologies such as the Microsoft HoloLens [1] and the Meta 2 [2] are being used to help designers realize new ways to design and collaborate.

In a metrology context, Augmented Reality (AR) methods could enable a more streamlined and efficient way to gauge part measurement, inspection, assembly and constraint data. Whilst this has to some extent been carried out in industry [3,8,18,19] the combination of augmented reality and metrology could lead to Immersive Metrology (IM), which has the potential to radically change how part inspection is undertaken, and by doing so enhance the value adding capability of being able to dynamically inspect a part in situ without handling it.

The aim of this paper is to document and describe an IM research framework, with a defined experimental methodology.

In order to achieve this aim the following objectives have been defined:

- To have a thorough understanding of the use of AR in manufacturing, particularly as a tool for verification and validation.
- To define the metrology information requirements at the time of assembly.
- To evaluate various AR technologies for displaying the required information and rank the technologies based on these findings.
- To develop a theoretical framework for increasing the metrology information availability at the time of assembly and inspection of a product.
- To create an experimental prototype that demonstrates the suitability of AR for verification and validation. In which IM can be tested, and put under varying circumstances to assess its performance.
- To discuss the results and identify limitations observed during the test case.

This paper is composed of a literature review that provides a brief background on AR in assembly which then identifies gaps and potential areas where this technology could be applied. It then introduces the research framework for IM followed by an explanation of the experimental approach that will be used to test the IM interface. Finally conclusions and future work are presented.

2. Literature Review

Augmented Reality is being used more and more in the engineering world as a tool to help engineers, and operators with training, design, manufacture, assembly and in some cases verification and validation of components [3]. This section will explain what AR is, how it works, current implementations in manufacturing and assembly, and finally how this technology has been used to help in the area of measurement and verification.

AR can be described as a human computer interaction system that blends the natural view that the user has of reality with digital information that can be of use at that point in time and place for the user. This digital information can be anything from videos, images, and text. What gets displayed will depend on the environment and current situation the user is in. This digital content if properly designed has the capability of enhancing or “augmenting” the reality that the user is experiencing. It is important to mention that contrary to Virtual Reality (VR) where the real world is blocked and what the user sees is a virtual scene, AR is achieved without the user losing sight of the real world. Hence why AR can be used for context-specific tasks, and has the potential to help in training, design, assembly verification and validation of components [4].

An AR system has four key components [3]:

- Video camera
- Tracking module
- Graphic Processing Unit (GPU)
- Display

The video camera captures the real world environment that the user is currently observing. Then the tracking module calculates in real time the actual position and orientation of the camera. Some consider this to be the most important component of an AR system [3] since without knowing the location of the camera or where the user is, the AR system does not know where to place the digital content. After the tracking module has successfully obtained the location and detected the markers, the GPU with this information now knows what it needs to display and where it needs to display it. Hence, it creates the digital information and passes it to the display in order for the user to see it. There are different type of AR displays. These are hand-held displays (smartphones, and tablets), monitors, projectors, and Head Mounted Displays (HMD). The display to be used depends on each application. The factors that determine this decision will be things such as available budget, access to technology, environment, task at hand, and if the user needs to have both hands free at all times. Figure 1 below shows an example of a hand held AR application.

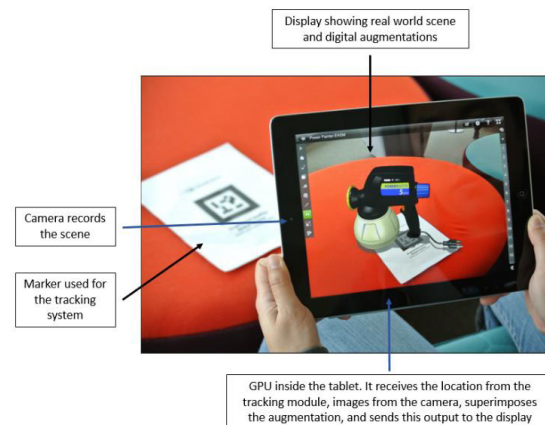


Fig.1. Representation of a hand held AR example setup. [5]

2.1. Augmented Reality in assembly

AR since its inception in the 1950's has been used for several types of applications such as in the entertainment industry, marketing campaigns, and finally to the industrial sector to try and help engineers and operators in training, design, and assembly guidance in a digital environment [20, 21]. According to Wang et al. [6] due to AR's ability to improve the interaction between computer systems and users by permitting them to move freely in an augmented environment and allow the users to interact with the objects naturally; AR technology has positioned itself as one of the most promising technologies to be able to assist in assembly processes.

In 2003, Tang et al. [7] did a comparative study between three different types of guided assembly methods. The first one was a paper based manual instruction set, the second was a Computer Assisted Instruction (CAI) method using a monitor as a display, and the third one used an AR HMD to overlay the assembly instructions over the workspace. The results showed

that using the AR system reduced the error rate for an assembly task by 82%, in particular cumulative errors. The results also showed through a measurement of the mental effort during the assembly that the mental workload was reduced with the AR system. Yamauchi et al. [8] successfully trialed a system composed of an optical shape measurement instrument and an AR HMD display system for a line heating task performed as part of the shipbuilding process. The system measured in real time the deformation of the plate and projected these results in a form of a line through the HMD for the operator to follow with his heating instrument in order to bend the plate to the desired shape.

In 2013, Wiedenmaier et al. [9] after comparing an expert guided assembly, an AR guided assembly, and a paper based assembly found that an assembly was completed in the shortest amount of time when an operator was guided by an expert, the second shortest completion time was an AR guided assembly, and in last place came a paper based guided assembly. Hou et al. [10] conducted an experimental study with 50 participants to test the possible cognitive gains of an AR assisted assembly system in comparison with a paper based instruction assembly. The findings showed that the AR system produced shorter completion times, less assembly errors, and lower total task load.

Xuyue et al. [11] created a mixed reality scene that displayed instructions to aid a technician through an assembly operation, resulting in an improvement in the efficiency of the manual operation, and a better user experience than compared to traditional training methods. Zhu et al. [12] created a guided assembly system that consisted of an AR HMD, and a virtual personal assistant. This system would provide an operator with visual, audio and locational cues. This system was used by a novice mechanic to successfully perform an advanced 33-step maintenance task on a military training vehicle. Vignais et al. [22] used AR to create a real-time ergonomic feedback system to prevent operators from getting injuries while in the assembly lines. The results showed that the system significantly reduced hazardous Rapid Upper Limb Assessment (RULA) values that are linked with increased risk for musculoskeletal disorders.

In 2014, Odenthal et al. [23] developed an Augmented Vision System (AVS) to support operators in error detection of small assemblies. They used the AVS system on a HMD, and on a table-mounted display. After trials with 48 subjects the study concluded that the use of the HMD significantly increases the error detection in assemblies.

In 2015, Syberfeldt et al. [13] after comparing an AR guided assembly system with a paper based assembly method found that all six participants in the study managed to complete the assembly without any errors, while two out of the six participants using the paper instructions did make assembly errors during the trial.

In 2016, Makris et al. [14] used an AR tool to develop a system that can help operators be in a hybrid human-robot collaborative industrial environment. This system was applied in an automotive case study demonstrating that the AR tool helped the operator feel more secure enhancing the operator's integration with the assembly process.

2.2 Gaps in AR for verification and validation of assemblies

The previous section described how AR systems have been used and tested to guide an assembly process. However, these studies came across areas that can be improved in order to fully integrate an AR system into an actual assembly process. The following are gaps found in the literature review regarding AR in verification and validation for an assembly process.

Daponte et al. [3] conducted a study on the current state of the art and future applications for AR in measurement. This study concluded that in order to be able to implement measurement systems based on AR the following key points need to be solved:

- To be able to fully incorporate the measurement instruments with the AR systems.
- To be able to present in a meaningful way the measurement data collected from the assembly process to the operator so it can be used properly.
- Continue the development of hybrid tracking technologies.
- Improvement of sensors and display technologies to reduce invasiveness of the AR interface.

In 2016 Wang et al. [6] conducted an in depth survey on the research performed on AR for assembly. They examined papers published from 1990 to 2015 that addressed AR for assembly. From the set of papers that were reviewed the ones that investigated AR in areas of assembly operation were selected for the study. After analyzing the papers and following the previous criteria 304 papers were selected for their study. The following were the gaps identified:

- Most AR assembly guidance systems focus only on providing a step-by-step instruction method, while failing to identify or provide guidance of the instructions in the assembly process.
- Due to most of the case studies being simple assemblies, future work should focus on the capability of an AR system to provide assistance in a complex, multi-step assembly task.
- Given that an AR interface could disturb or interrupt an ongoing assembly task, it is important to research the ability to detect and recognize the operator's actions in order to provide a true industrial hands free system.

The following section presents the IM framework which will address the research gaps identified.

3. Research Framework for IM

This section presents the research framework for IM. The purpose of this is to form the experimental methodology which will be used to undertake defined experimental work using the augmented metrology setup and a range of case studies. The framework will identify the critical phases in establishing a cohesive set of experimental guidelines with which to formulate robust conclusive outputs.

3.1 Phases of the Research Framework

The framework is split into 5 phases: 1) Literature Review; 2) Assessment of current AR technology; 3) Identification of the components of an IM interface; 4) Development of an IM experimental prototype; 5) Analysis of results.

Figure 2 illustrates the key stages of the research framework for an IM interface.

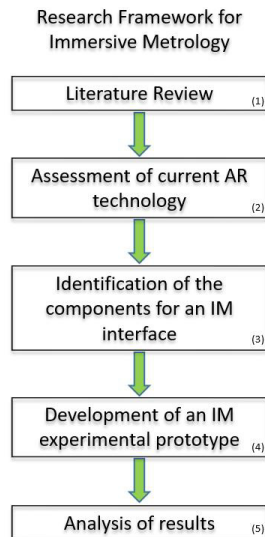


Fig. 2 Phases of the Research Framework for IM

1. A review investigating the following areas will be conducted: metrology best practices, current metrology procedures, standards, and results obtained from industry study cases on measurement-assisted assembly that investigate the metrology key requirements needed at the time of inspection. It is of crucial importance to be able to identify what information and when it needs to be displayed to the operator in order for him/her to be able to perform the verification and validation of the assembly. Hence this information will be obtained from the metrology best practice guide from the National Physical Laboratory (NPL) called "*Fundamental good practice in dimensional metrology guide*" [15], current metrology procedures from the equipment suppliers, standards defined in the industry, and from results obtained from previous measurement-assisted assembly case study that were conducted in the aerospace industry.
2. A comparison of the requirements, advantages and disadvantages of each of the different AR technologies will be performed. Once this information is obtained each technology can be assessed based on these findings and subsequently ranked based on suitability for IM. It is important to identify early in the process the suitability of each AR technology to be used in an IM application in order to identify the necessary knowledge, and components that will be required to be able to use this technology properly and exploit its full capabilities. The technologies that will be

investigated will be the Microsoft HoloLens [1], and the Meta 2 [2].

3. It is then necessary to identify the inputs, controls, mechanisms, and outputs of the IM metrology system. This would enable the user to visualize where the IM metrology interface stands in the process. Therefore, this allows for an understanding of the impact each variable has on the system as well as the consequences if they are not properly addressed.
4. After identifying the components of the AR metrology system and what roles each component plays, it is then possible to start the design of a prototype that takes into account these findings and be tested through a defined case study. Trials would be conducted in a metrology lab where participants will be asked to assemble a panel for an actual satellite module. The IM app will take the participants through the assembly process as well as the verification of the component; thus striving for measurement-assisted assembly.
5. Once the case study has been completed the data will be analysed to assess the IM metrology process within the context of assembly and inspection. The results will be discussed in relation to existing literature.

4. Development of an IM experimental prototype

The experimental approach mentioned in step number 4 of Figure 2 consists of 6 stages: 1) Test definition; 2) Participant selection; 3) Performance of tests; 4) Data capture; 5) User assessment; and 6) Outcomes of the research.

Figure 3 illustrates the phases of the experimental approach that will be used.

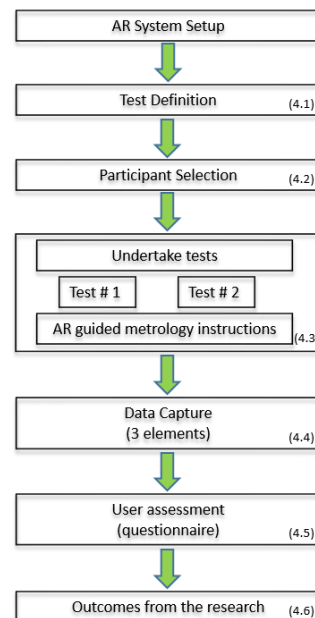


Fig. 3 Experimental approach used for IM

4.1. Test Definition

Two types of tests will be performed by the selected participants. The test types will consist of a pre-test and a formal technology demonstrator test. The pre-test will be a simple assembly (a basic Lego model) designed to familiarize the participant with the technology and provide a degree of understanding. Following this assembly, the participants will be asked to take part in the technology demonstrator for the IM tool in which they will be assembling a complex component. The component to be assembled is a panel of a module from an actual satellite. The reasons why this was chosen is because it is an assembly that could not be put together by an individual without instructions, or prior expertise. It is also a component that requires a high degree of accuracy and specialized metrology equipment (laser tracker) that needs to be used in order to verify if the component is assembled correctly. Thus this test will be replicating an actual industrial scenario in which IM could be used.

4.2. Participant Selection

The participants chosen for these trials will be people with an engineering background who have a degree of familiarity with assemblies and mechanical components. The reason for this is because it is likely that the IM tool will be used by people with this type of background, and also the feedback that they can provide could prove to be valuable in the development of the IM tool.

4.3. Performance of tests

The IM tool will guide an inexperienced user in the area of metrology and assembly, taking them through the complete process. This will involve setting up of metrology hardware, completing the necessary metrology best practices as defined in the NPL document [15], assembly of the panel to the satellite module, and finally as the assembly progresses the tool will prompt and guide the user to perform the corresponding measurements to ensure that the component is being assembled correctly.

The setup guidance as well as the metrology best practices will include taking the participant or in the future any user through the following stages:

- Setup: Easy to follow instructions on how to properly set-up the metrology hardware from its storage place, warm up (if needed), how to perform the needed calibrations or field checks, setting of a reference system, correct positioning of scale bars or targets needed, and how to connect the hardware with a metrology software such as, Spatial Analyzer [16].
- Location: This refers to how to properly set up a datum point (also known as reference frame) of the object to be measured. This step is crucial in order to perform a successful measurement. After the datum point has been established the IM tool will then take the operator through steps on how to locate the measurement equipment in space

relative to the component reference frame in order to take the corresponding measurements.

Furthermore once the user has finished performing a verification stage the IM tool will automatically log this instance in a report that can later be accessed by a supervisor to inspect the quality of the job, or if there was an issue with the assembly and be able to see what were the potential causes. These reports can also help with all traceability requirements.

4.4. Data Capture

In an effort to measure the effectiveness and usability of the IM tool, the data to be captured during these trials and then further analysed will be as follows:

- Time taken to complete the assembly and verification processes.
- Number of errors committed.
- Number of accurate stages completed.

4.5. User assessment

The following questionnaire will be used to assess the ease of use, satisfaction level, and approval of the IM tool. This questionnaire was used in Syberfeldt et al. [13] research, in their comparative study consisting of seven questions that are each graded on a Likert scale [17] from 1 to 7 (1 = totally agree, 7 = totally disagree). It has been adapted to fit the purpose of this research:

- 1) I found the IM tool easy to understand.
- 2) I found it easy to use the IM tool to do the assembly and perform the verifications needed.
- 3) I felt that I performed quickly with the IM tool.
- 4) If I had to use an IM tool like this on a regular basis, this is a technique I would appreciate having available.
- 5) I found the IM tool physically demanding.
- 6) I found the IM tool mentally demanding.
- 7) I found the IM tool frustrating.

4.6. Outcomes from this research

After this data has been gathered, it will be analysed to see what parts of the IM tool functioned correctly, what could be improved, and if this tool can be used to guide an engineer or an assembly operator through a verification and validation process without them having prior knowledge on how to perform these tasks.

5. Conclusions and future work

A framework and an experimental approach for the development of an IM tool that aims to increase the availability of metrology knowledge during assembly through the use of an AR interface was described and detailed.

The IM tool in question has the potential to assist an operator in the following areas:

- Provide guidance on the assembly process.
- Take the operator through the verification and validation procedure by providing a step-by step guidance explaining the correct procedures, and best practices that otherwise could not have been performed by himself/herself unless there was a metrologist expert present.
- Provide real time feedback on the quality of the assembly (go or no go approach).
- Reduce incorrect measurements and procedures.
- Provide an enhanced and automated report of the assembly, and verification results for traceability requirements.

This framework will be evaluated in a case study that will take a participant with no prior knowledge of metrology through the process of assembling and verifying a complex aerospace component that requires the use of specialized metrology equipment and knowledge. The experience gained from this will be used to continue the IM research and development.

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